Locating a Cement Distribution Facility using the Centre of Gravity (COG) Model: A Case Study

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Abstract
Since 2017, there has been a very high demand for cement from end-users in the country. This demand is resulting in the high production of cement in various cement factories, especially in LEOCEM, to meet their customers' demands. The bottleneck between this demand and supply is the timely delivery of cement to various cities in the four regions (Eastern, Western, Northern, and Southern) within the country. A huge pile of heavy-duty trucks storms the factory yard, waiting to be loaded for distribution in various cities and regions of the country. The aspect of transportation for timely delivery to distributors and cost has not been managed well to meet the customers' demand over the years. This study focuses on locating a central warehouse or nearest point of cement distribution in the cities of the various regions, using the Distance-Based Approach, considering the weighted demand of customers all over the country. This is to mitigate the cost of transportation, reduce the time of delivery, and stabilize the profit margin of the company. The data collected was analyzed using Excel Solver to solve the facility location and demand weighted problem. The overall network structure of the study consists of three levels: cement production plants on the first level, Distribution Centres (DCs) on the second one, and customers on the third level. The modeling choices used in this study can be relevant in other industrial contexts as well. The study introduces a clustering-based approach to model vehicle routing, minimum volume constraints to ensure full truckload transport, minimum and maximum throughput constraints on DCs, maximum covering distance constraints, and single-sourcing restrictions.

Keywords
Location-routing, Minimum volume constraints, Throughput, Distribution Centres (DCs), Plants

1. Introduction
Over the past years, facility location using the Distance-Based Approach model for Supply Chain and Network Design has been used by many researchers. Solving a Supply Chain Network Design problem using the Centre of Gravity (COG) model for a Cement Manufacturing and Distribution Company in Sierra Leone is of absolute relevance with regards to the underlying problems of the weighted demand of cement products.

In this study, it is found that only wholesalers are recorders for customers to access products, and they are relatively not close enough to the customer. Hence, there are no warehousing facilities in the major cities/regions of the country to hold a larger amount of cement products so that the customers' demands are met significantly. Most customers who visited the wholesalers to access products sometimes experienced no availability of the product and, of course, congestion/overcrowding at the spot of the wholesalers.

In Sierra Leone, cement manufacturing and distribution companies are purely located in Freetown, the capital city, with high demand for cement products hurling from the other parts of the country's four main regions. To ensure the products reach every part of the country, road freight vehicles are used to deliver cement products only to wholesalers at various points, thereby experiencing price increments for retailers and consumers.

This process sometimes results in a huge drought of the products from the side of the wholesalers, since the product delivery vehicles are expected to move from the city to other parts of the country. The vehicle has to be parked for several days to ensure loading of the products before leaving for the interiors. A huge amount of time has been consumed in order to satisfy customer/weighted demands.

It is of importance for this study, which analyses the weighted demand for cement products in the 9 major cities in 4 main regions in the country. This is to minimize the time spent by vehicles to convey products to various regions, the distance to be covered by road freight to convey products, and the resources involved in meeting the consumers' demands.

Objective

The alignment of networks and their relevant locations and capacity can be considered as an appropriate and distinctive supply chain network. Relevant information channels on product delivery can be one of the many decisions in successful supply chain management that have an overall impact on service delivery and average profit returns. It is possible that most companies may have various decision rules with regard to demography and facility location.

The main objective of this study is to determine cement DCs and facility locations at strategic points to serve the major cities in all four regions of the country (Sierra Leone) to enhance customers' weighted demand. Establishing new sites and locations will enable the optimization of customers' demand, profit merging, and overcome the timeliness of product delivery to final destinations. Assuming that the number and location of the plants as well as the number and location of the customers are fixed, given the demand of customers and a list of probable DCs, the major concern is to locate DCs and assign customers to them in such a way as to minimize the total distribution costs and time of delivery.

2. Literature Review

The goal of the location problem addressed in this paper is to identify the locations of the new facilities to capture as much of the available demand as possible, i.e., to control the amount of demand lost due to lack of coverage and congestion. An important feature of our model is that it assumes that each customer will tend to patronize the most convenient (i.e., closest) open facility (Berman et al., 2006).

The Clustering-based location-allocation method to the Capacitated Facility Location Problem (CFLP) provides an approximately optimal solution to determine the location and coverage of a set of facilities to serve the demands of a large number of locations. The allocation is constrained by facility capacities. Even though different facilities may have different capacities, the overall capacity may be inadequate to satisfy the total demands (Liao et al., 2008).

Many businesses in the world critically focus on the location of their facilities or warehouses in order to efficiently satisfy customer demand. To achieve this, companies embark on an extensive survey that produces probabilistic data in accordance with the distance based on facility location problem (Ashish et al., 2018).
Decisions about the distribution system are a strategic issue for almost every company. The problem of locating facilities and allocating customers covers the core components of distribution system design. Industrial firms must locate fabrication and assembly plants as well as warehouses. Stores have to be located near retail outlets. The ability to manufacture and market its products is dependent in part on the location of the facilities (Klose et al., 2005).

An important consideration in urban and regional planning is where to locate facilities providing services. Location models are typically used to support facility siting decisions (Farhan et al., 2006).

It is a waste of time to locate new facilities in the plane when existing facilities are already in place. The objective is to minimize the weighted sum of rectilinear distances. Necessary and sufficient conditions for optimality are established. We show that the optimum locations of the new facilities are dependent on the relative orderings of old facilities along the two coordinate axes but not on the distances between them (Picard et al., 1978).

A location model is said to be about competitive facilities when it explicitly incorporates the fact that other facilities are already (or will be) present in the market and that the new facility (ies) will have to compete with them for its (their) market share. The apparent simplicity of this statement hides several implicit and explicit notions that have to be made more precise before a clear and well-defined model arises (Platra, F. 2001). *A strategic decision that has a direct impact on* the success of disaster response operations is the location of facilities for prepositioning supplies to be used during a disaster. Locating such facilities close to disaster-prone areas is of utmost importance to minimize response time. However, this is risky because the facility may be disrupted, and thus the demand point(s) may not be supported (Akgün et al., 2015).

Facility location models deal, for the most part, with the location of plants, warehouses, distribution centres, and other industrial facilities. These location models do not account for competition or for differences among facilities and, therefore, allocate consumers to facilities by proximity. In reality, retail facilities operate in a competitive environment with the objective of profit and market share maximization. These facilities are different from each other in their overall attractiveness to consumers (Drezner, T. 2014).

3. Research methods

3.1 Data collection

The research methodology implored in this study is qualitative and quantitative data collection techniques. The data collection techniques used the primary data and secondary data approaches which are empirical data and from desk review of other researches on similar studies.

Table 1. Data of major cities in Sierra Leone

	City	Region	Population	Latitude	Longitude
1	Freetown	Western Area	802,639	8.487	-13.236
2	Bo	Sothern Area	174,354	7.965	-11.738
3	Kenema	Eastern Province	143,137	7.877	-11.738
4	Kono		88,000	8.644	-10.971
5	Kailahun		14,085	8.644	-10.573
6	Makeni	Northern Province	87,676	8.886	-12.044
7	Lunsar		22,461	8.684	-12.535
8	Port Loko		21,308	8.766	-12.787
9	Kambia		17,948	9.589	-11.553

Table 1 shows the population data of nine (9) cities in the four main regions of Sierra Leone and their longitude and latitude. This shows the population and weighted demand for cement in the country. A warehouse should be located in strategic locations that will serve the demand population and minimize the cost and distance of the location. Hence, the cement factory is located in the capital city of Freetown.

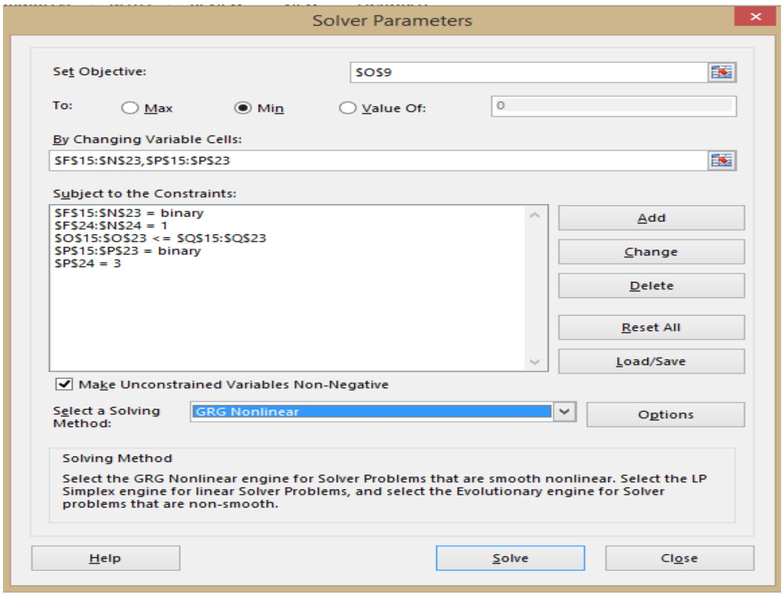

Figure 1. Solver Parameters

a. Data processing

Data processing of this study to solve the facility location of the cement manufacturing and distribution centre implored the Excel Solver. The Excel Solver is a Microsoft Excel add-in program used for what-if analysis to find an optimal (maximum or minimum) value for a formula in one cell called the objective cell, subject to constraints, or limits, on the values of other formula cells on a worksheet. The Solver works with a group of cells called decision variables, or simply variable cells, that are used in computing the formulas in the objective and constraint cells. The Solver adjusts the values in the decision variable cells to satisfy the limits on constraint cells and produce the result you want for the objective cell. https://support.microsoft.com/en-us/office/.

Figure 1shows the platform that holds constraints with decision variables. The analysis and processing of data is to find the best location for three (**3**) key warehouses that will serve the nine (9) cities listed in Table 1 (data of major cities in Sierra Leone). Hence, the distance between the facility and the analysis/processing facility is minimized.

4. Result analysis and Discussion

The Network Design study objective is to minimize the total distance where by a Distribution Centre (DC)/warehouse is located at a point that will serve other cities thus the total distance is minimized. From the study conducted for nine (9) cities in four regions, Figure 2 shows the distance covered from each of the nine cities with a total distance is **324 miles** which is equivalent to **521.316 km**. Hence that the quantitative technique used is to determine the optimal location of a facility base upon minimizing the transportation cost between the production centre and the distribution centre.

Distance	Freetown	Bo	Kenema	Kono	Kailahun	Makeni	Lunsar	Port Loko	Kabala	Total Old Distance
Freetown	0	108	145	103	157	85	67	56	162	324
Bo	108	0	38	48	45	66	102	135	167	
Kenema	145	38	0	76	47	91	164	172	182	
Kono	103	48	76	0	138	68	78	93	62	
Kailahun	157	45	47	138	0	142	127	135	143	
Makeni	85	66	91	68	142	0	35	56	70	
Lunsar	67	102	164	78	127	35	0	27	105	
Port Loko	56	135	172	93	135	56	27	0	142	
Kabala	162	167	182	62	143	70	105	142	0	

Figure 2. Distance of nine cities in miles

Distance	Freetown	Bo	Kenema	Kono	Kailahun	Makeni	Lunsar	Port Loko	Kabala	Total warehouse to be served	Warehouse to be established	No of state serve
Freetown	1	0	0	0	0	0	0	0	0	1	1	9
Bo	0	1	1	0	1	0	0	0	0	3	1	9
Kenema	0	0	0	0	0	0	0	0	0	0	0	0
Kono	0	0	0	1	0	1	0	0	0	2	1	9
Kailahun	0	0	0	0	0	0	0	0	0	0	0	0
Makeni	0	0	0	1	0	1	1	0	1	4	1	9
Lunsar	0	0	0	0	0	0	0	0	0	0	0	0
Port Loko	0	0	0	0	0	0	0	0	0	0	0	0
Kabala	0	0	0	0	0	0	0	0	0	0	0	0
Total warehouse	1	1	1	2	1	2	1	0	1		4	

Figure 3. Cities with DCs/Warehouse

In Figure 3, the yellow shaded cells show the warehouses established in each city. The data before the excel solver analysis shows that, a total number of 10 warehouses/ DCs to be served by all the nine cities. Freetown is

DC is serving it population with one warehouse, Bo warehouse is to serve the population of 3 cities including Bo itself, Kono DC is to serve the population of 2 cities and Makeni DC is to serve the population 4 cities. The number of warehouse/DCs determined to serve all of the 9 Cities is 4 in other to minimize the total distance.

Excel Solver Output

Excel Solver New Minimized Total Distance
292

Distance	Freetown	Bo	Kenema	Kono	Kailahun	Makeni	Lunsar	Port Loko	Kabala	Total warehouse to be served	Warehouse to be established	No of state serve
Freetown	1	0	0	0	0	0	0	1	0	2	1	9
Bo	0	1	1	1	1	0	0	0	0	4	1	9
Kenema	0	0	0	0	0	0	0	0	0	0	0	0
Kono	0	0	0	0	0	0	0	0	0	0	0	0
Kailahun	0	0	0	0	0	0	0	0	0	0	0	0
Makeni	0	0	0	0	0	1	1	0	1	3	1	9
Lunsar	0	0	0	0	0	0	0	0	0	0	0	0
Port Loko	0	0	0	0	0	0	0	0	0	0	0	0
Kabala	0	0	0	0	0	0	0	0	0	0	0	0
Total warehouse serving	1	1	1	1	1	1	1	1	1		3	

Figure 4. Excel solver output

Figure 4 is designed with different cells that match colours. Each coloured cell on the row has been matched to the cells in the column of the same colour. This diagram depicts the number and location of warehouse/DCs, as well as the cities they will serve.

After the excel solver analysis, Figure 4 shows that a total of 3 warehouse/DCs are to be established that will serve all the 9 cities with a total distance of **292 miles,** which is equivalent to **469.828 km**. The warehouses/DCs will be located in cities from the row side, and the column will show which cities each warehouse/DC will serve.

The result shows that 1 warehouse/DC located in **Freetown** will serve the population of Freetown and Port Loko, 1 warehouse/DC located in **Bo** will serve the population of Bo, Kenema, Kono, and Kailahun, and 1 warehouse/DC located in **Makeni** will serve the population of Makeni, Lunsar, and Kabala with a reduced total distance.

5. Conclusions

Freetown, which is the capital of Sierra Leone, holds the manufacturing facility that is used to serve all other cities in the various regions' populations with one warehouse. It apparently resulted in a lot of time and resources being consumed in order to meet consumers' demands in the various regions with a total distance of 324 miles, which is equivalent to 521.316 km to be covered.

Therefore, the study shows that the Excel solver tool and data processing methodology used to address the problem of weighted demand and facility location of LEOCEM Cement Manufacturing and Distribution Company have calculated a total number of 3 warehouses/DCs to be established in the country to serve the population of the 9 major cities in Sierra Leone with a reduced total distance of **292 miles,** which is equivalent to **469.828 km.** This will enable the company to overcome delays in product delivery to consumers from the various cities. The warehouses/DCs will hold a maximum number of cement products. This will overcome the excess movement of road freight since it emits greenhouse gases that are not environmentally friendly.

This research should be used by other researchers even though it is not considered the final methodology to calculate the location of facilities using the Distance Based Approach model.

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Biographie

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